DETR
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GENERAL INFORMATION LEAFLET 83

Domestic boiler anti-cycling controls

An evaluation

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BEST PRACTICE PROGRAMME

ENERGY EFFICIENCY
DEPARTMENT OF THE ENVIRONMENT,
TRANSPORT AND THE REGIONS

BEST PRACTICE
PROGRAMME

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INTRODUCTION

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For many years a range of domestic heating controls has been available. In addition to proven standard controls, such as programmers, thermostatic radiator valves (TRVs), room thermostats and cylinder thermostats, there are also a number of types of boiler anti-cycling controls. These 'add-on' controls are designed to override the boiler thermostat and reduce unnecessary boiler dry cycling (see below).

Potential energy savings are often claimed for these devices, ranging from 5%-40%. If these claims were true the products could have a major role in reducing the energy usage in domestic and commercial buildings. Unfortunately, there is little substantiated evidence to confirm their effectiveness. Therefore, in order to provide an independent assessment of the generic products, an evaluation project was undertaken.

The project was managed by BRECSU and BG plc Research & Technology, on behalf of the Department of the Environment, Transport and the Regions (DETR), with technical contributions from the Building Research Establishment Ltd (BRE), the Association of Controls Manufacturers (TACMA) and South Bank University. The aim of the project was to investigate the performance of anti-cycling controls intended for use in domestic buildings.

WHAT ARE ANTI-CYCLING DEVICES?

Boiler dry cycling occurs when the boiler fires without a demand for heat from the heating system that it supplies, leading to wastage of fuel.

The conventional way to reduce dry cycling and fuel wastage is to fit heating controls to the minimum recommended standards; using room and cylinder thermostats, motorized valve(s) and hard wiring them to the boiler. This wiring provides an interlock, allowing the controls equipment to shut off the boiler when heat is not required and thus significantly reducing boiler cycling. Without this feature, or in systems without effective hot water control, the boiler thermostat will cause the boiler to fire for brief periods just to maintain its own temperature.

The basic principle behind the anti-cycling control is to reduce the number of times the boiler fires while maintaining the required hot water and central heating temperatures. There is a range of products available which have an anti-cycling function. These are available in three main forms for both the domestic and commercial markets:

- stand-alone 'add-on' controls
- part of integrated control units
- part of internal boiler controls.

This study concentrates only on the stand-alone products. They are generally units which are not part of an initial heating and hot water control strategy, but are retrospectively added to the system to supplement any existing controls.

The greatest potential for savings from these products is on badly controlled systems, with old, high-thermal-capacity boilers. These boilers have poor part-load efficiencies and could therefore benefit from a system designed to reduce cycling. However, most modern domestic central heating boilers have very high efficiencies which are maintained even at low loads. Consequently, the energy losses due to cycling are much reduced with these boilers, and the benefit of applying an anti-cycling control is likely to be small.

The study was designed to measure the fuel savings resulting from the use of examples of the stand-alone units, and the effects on space and hot water temperatures. Representative models from each of the three types of stand-alone anti-cycling controls were assessed:

- **Type A: Simple time delay units.** The simple time delay unit is connected into the existing boiler wiring between the thermostat and the gas valve or boiler control unit. When there is a demand for heat, the control prevents the boiler from firing for a fixed period, usually 1-10 minutes, regardless of the conditions within the system.

- **Type B: Delayed thermal response units with return temperature sensor.** This type of control is installed in existing boiler wiring in

EXPERIMENTAL PROJECT DESCRIPTION

the same manner as the simple time delay unit, but includes a return pipe temperature sensor. The Type B control is essentially an electronic boiler thermostat linked to a simple delay timer, and provides a manually set delay period at given boiler return temperatures.

- **Type C: Delayed thermal response units with the capability of automatically adjusting the delay period dependent on boiler load.** This type of control is more sophisticated and usually incorporates a simple microprocessor as a means of determining the boiler load upon which the boiler firing delay is based. There are two basic types of control:
  - *Units with electronic temperature sensors which are more sensitive than the conventional boiler thermostat.* The control interrupts the boiler as with the simple units, but the delay period is determined by monitoring the rate of change of the boiler flow or return temperature. The unit automatically varies the frequency and length of boiler firing to meet the appropriate load.
  - *Units that work on the relationship between the on-to-off ratio of the boiler thermostat and the load requirements.* The control monitors the requests for heat which are made when the boiler is off, and a variable delay timer then forces the boiler to wait for a calculated period before firing. This delay is usually a percentage of the actual boiler thermostat off time.

EXPERIMENTAL PROJECT DESCRIPTION

Using the information supplied from a market study, a number of commercially available units were selected for evaluation. These units were first evaluated in the laboratory to confirm that their specification or function was as claimed by the manufacturers, and also that they had been correctly categorized. Following this, three devices were selected as best examples of the three generic groups referred to above as type A, type B and type C.

Two similar four-bedroom houses in Didcot, Oxfordshire were used for the evaluations. The houses were of the same design, with a similar heat demand. However, there were small differences between the performance of each house, therefore direct comparisons between the performance of devices in different houses were not made. However, indicative comparisons are still valid.

The two houses were fitted with different heating systems.

- In house 1, an older type wall-hung cast iron boiler was installed with a 'well-controlled' fully pumped system. The system was intended to represent a typical older type central heating system, with a good practice minimum recommended control system[1]. This included time control, room and cylinder thermostats, motorized valves and boiler interlock.
- In house 2, a floor-standing cast iron boiler was installed with a gravity-fed hot water circuit and a pumped heating circuit. This system is termed 'inadequately controlled' and represents a typical older type semi-gravity system, with a room thermostat controlling the pump and simple time switch control.

Two different anti-cycling controls were fitted in each house and the system was arranged so that either or none could be selected. In house 1 (well-controlled) type B and type C were fitted, and in house 2 (inadequately controlled) type A and type B. The addition of a cylinder thermostat and a two-port motorized valve wired to provide boiler interlock was also tested on the semi-gravity system (house 2).

The evaluation programme was split into two parts – summer hot water tests, and winter space heating and hot water tests.

Summer hot water tests

The summer hot water tests were carried out during the months with no space heating demand to evaluate the effects of the devices on hot water energy usage. Hot water usage was simulated using a programmed hot water draw-off schedule representative of national average domestic hot water consumption. To avoid inconsistencies due to changes in the stored water temperature, the system was arranged so that differing levels of water were drawn to maintain the same draw-off of energy. In addition, the temperature of the water in the storage tank was measured at different heights in the tank.

EXPERIMENTAL AND ANALYTICAL RESULTS

Winter space heating and hot water tests

This part of the experimental work was carried out in the heating season, October 1995 to May 1996, and represents typical space heating and hot water loads. The hot water demands were set to the same regime as for the summer hot water tests. Space heating demands were set up to standard domestic usage. An electro-mechanical room thermostat (located in the lounge) and a basic time switch controlled the 12-radiator system. The thermostats were set to give a nominal lounge temperature of 21°C, the radiators in each room balanced to give an 11°C temperature drop between flow and return. The heating ON times were 07.00 to 11.30 and 16.30 to 22.30, allowing provision for space heating and hot water at the same times.

As well as collecting test data, the houses were operated in 'reference mode' to allow calibration data to be collected. These reference periods were timed to cover the different times of year, and the different test operations. This gave reference consumption data for the two test houses without the anti-cycling controls operating, and under varied weather conditions.

EXPERIMENTAL AND ANALYTICAL RESULTS

Following a statistical analysis of the data a number of relevant results have been established. These can be split into several areas:

- boiler cycling
- boiler efficiency
- summer hot water
- space heating and hot water (heating season)
- performance of the heating system.

Boiler cycling

The primary function of an anti-cycling controller is to reduce the number of boiler cycles, thus reducing dry cycling. Such a reduction in cycling can affect boiler efficiencies. Throughout the monitoring period each boiler cycle was measured and counted, allowing a direct comparison between the cycling regime with and without the controls in operation. Results for both summer hot water tests and winter hot water and space heating tests are shown in table 1.

It is clear from these results that both the anti-cycling controls and the cylinder thermostat significantly reduce boiler cycling under both test regimes. This is, however, only of value if these reductions lead to either an increase in boiler efficiency or a reduction in the gas consumption of the system, while maintaining satisfactory performance.

Boiler efficiencies

The efficiency of the boiler installed in house 1 was measured. Average yearly figures are shown in table 2. The small differences in efficiency both during the summer and winter are within the normal accuracy of boiler efficiency measurements and, therefore, must be treated as insignificant. The efficiencies achieved are fully representative of older type cast iron boilers with permanent pilot ignition. It is concluded that the reductions in boiler cycles have no effect on boiler efficiencies.

House	Model	Summer hot water		Winter space heating and hot water	
		Average daily boiler cycles	Reduction %	Average daily boiler cycles	Reduction %
House 1 – fully pumped system	*Reference*	*31*	–	*57*	–
	Type B	16	48	16	72
	Type C	14	55	17	70
House 2 – semi-gravity system	*Reference*	*79*	–	*54*	–
	Type B	50	37	12	78
	Type A	36	54	20	62
	Cylinder stat	28	65	18	67

Table 1 The effect of different devices on boiler cycles

EXPERIMENTAL AND ANALYTICAL RESULTS

Summer hot water

The measurement of the performance of the system during the summer hot water only period provided gas consumption figures for operation in reference mode and for each control type (table 3). Conclusions from the summer tests, based upon the performance of the system, are as follows.

- In a well-controlled, fully pumped system (house 1) the use of each anti-cycling device has no significant effect on gas consumption. However, the recovery time of the cylinder is significantly increased, thus decreasing the level of service provided by the system (see figure 1).
- In a semi-gravity system without hot water control (house 2), the use of either type A, type B or a cylinder thermostat achieved gas consumption savings. The largest savings were achieved by the installation of the cylinder thermostat and two-port valve. Anti-cycling devices and the cylinder thermostat achieved fuel savings with similar average tank temperatures. However, the cylinder thermostat was able to take control of hot water temperatures. With the use of each anti-cycling device the hot water temperatures are only controlled by the boiler thermostat. Very high water temperatures could still occur with the use of the anti-cycling controls without the additional use of a cylinder thermostat.

It should be noted that the summer hot water energy consumption is only between 16% and 22% of the annual space heating and hot water costs.

Control	Summer efficiency %	Winter efficiency %
(House 1)		
Reference system	*51.4*	*67.5*
Type B	51.9	66.8
Type C	52.3	65.4

Table 2 Boiler efficiencies

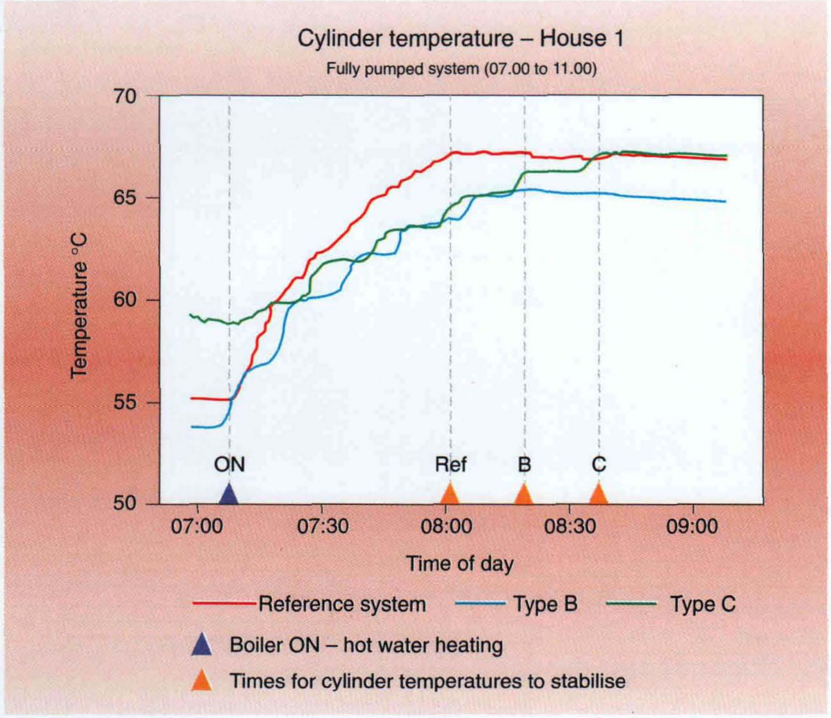

Figure 1 Typical recovery times of the hot water cylinder

House	Model	Average summer gas consumption MJ/day	Saving %	Average cylinder temp °C	Cold water feed temp °C
House 1 – fully pumped system	*Reference*	*92*	–	*57.2*	*17.4*
	Type B	93	-1	57.9	18.6
	Type C	95	-3	58.8	18.5
House 2 – semi-gravity system	*Reference*	*133*	–	*81.4*	*18.9*
	Type B	120	10	77.9	18.5
	Type A	109	18	69.6	18.5
	Cylinder stat	105	21	63.8	16.6

Table 3 Summer operation – energy savings

EXPERIMENTAL AND ANALYTICAL RESULTS

Space heating and hot water (heating season)

The winter space heating and hot water tests represent the majority of the gas consumption for the average year. Each device was measured for several months, then a modelling technique was used to predict results for the whole winter period[2]. The technique used the measured data together with the twenty-year average weather data to predict gas consumptions. The results of this analysis are demonstrated in figures 2 and 3 and in table 4.

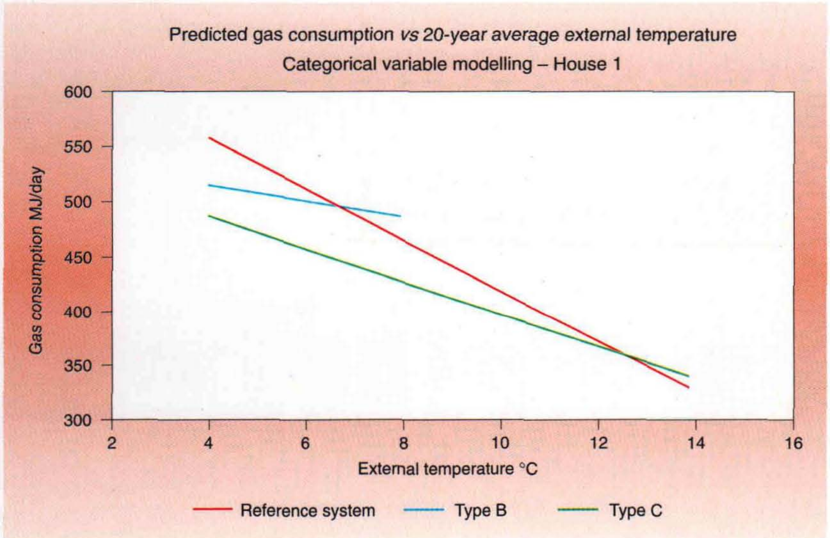

Figure 2

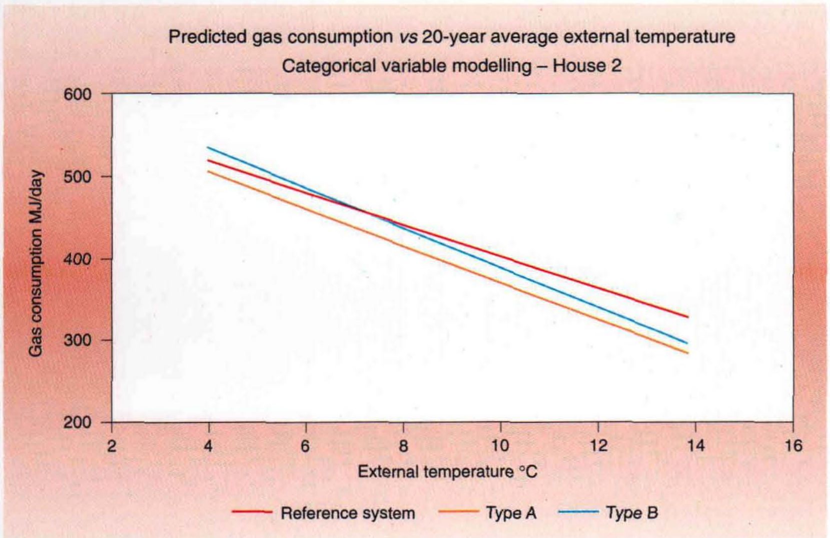

Figure 3

In the fully pumped system (house 1) the performances of the two types of controller differ significantly (see figure 2). The predicted gas consumptions for the type C device are consistently below the reference figures. However, as outside temperature increases relative to the reference, fuel consumption also increases.

The gas consumptions predicted for type B are less than the reference levels (see figure 2), but as the external temperature rises to 7°C the consumptions tend to increase. It was not possible to project the performance of this device at external temperatures above 8°C because such conditions were not encountered during the experimental procedure. The projected performance, therefore, is not illustrated on the graph, but for calculation purposes it was assumed to be the same as in the reference situation. Savings figures shown in table 4 are calculated using this method.

In the semi-gravity system (house 2) the effects of the controls are more consistent (figure 3). The predicted consumption for the type A control consistently shows a small saving throughout the range of temperatures. The type B device causes a slight increase in consumption at low temperatures; above 8°C slight reductions are predicted.

The modelling methodology allows overall gas consumption savings to be calculated for each type of device. These are summarized in table 4. The range of savings indicates the likely maximum and minimum percentage savings obtainable for each device based on a confidence interval analysis of the regression equations.

The reduction in gas consumptions demonstrated in figures 2 and 3 and in table 4 can only be true energy savings if the performance of the heating system is not reduced.

Performance of the heating system

The performance of the heating system was measured in two ways – the supply of hot water and the internal air temperatures maintained in the houses. The performance of the system for the provision of hot water during the summer months is described

EXPERIMENTAL AND ANALYTICAL RESULTS

House	Model	Average gas consumption MJ/day	Savings %	Range of savings %
House 1 – fully pumped system	*Reference* Type B Type C	*488* 495 443	– -1.5 9	– -2 to +2 8 to 11
House 2 – semi-gravity system	*Reference* Type B Type A	*462* 462 440	– 0 4.5	– 0 to 0.5 4 to 5

***Table 4** Predicted daily gas consumptions for space and hot water heating during the winter heating season*

House	Model	Average house temperatures 20.00-22.00 hrs	Difference °C
House 1 – fully pumped system	*Reference* Type B Type C	*22.9* 20.6 20.9	– -2.3 -2.0
House 2 – semi-gravity system	*Reference* Type B Type A	*21.3* 21.4 20.3	– 0.1 -1.0

***Table 5** Average measured room temperatures*

earlier. It is assumed that the performance of this part of the system is the same during the winter heating period. The performance of the space heating element of the system is more difficult to identify.

The purpose of the space heating system is to supply space heating to achieve and maintain internal air temperatures at the times, and to the levels set by the control system. Air temperatures were monitored in a number of locations in each house. The temperature in the lounge, where the room thermostat was positioned, combined with other room temperatures, was used to assess the effect of the devices on room temperatures.

Only temperatures measured between 20.00 and 22.00 hours were used, because during these times system conditions are steady without solar influence, and the boiler always cycles on the room thermostat. Any variation in the average temperature between the reference and controls test periods will be due entirely to the effect of the control device.

The average house temperatures in each of the test periods are shown in table 5.

The temperature reductions shown in table 5 indicate that during three of the test periods the performance of the heating system was reduced. These three examples are the same as those shown to provide predicted gas consumption savings as shown in table 4. It is concluded that the reduced space heating system performance is a consequence of the control regime imposed by the anti-cycling devices, and that it is this reduction in performance that is the main reason for the gas consumption savings. It should be noted that any manual reduction of set temperatures on room thermostats would also reduce gas consumption.

CONCLUSIONS

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- The use of all anti-cycling control devices led to a large reduction in boiler cycling, but without any significant effect on boiler efficiencies.
- The devices installed and tested in the well-controlled, fully pumped system (house 1) led to insignificant savings during the summer hot water period.
- The devices tested in the poorly controlled system (house 2) led to significant savings in gas consumption of up to 18% during the summer period. However, a cylinder thermostat and two-port valve installed in the same system led to higher savings of 21%. Both devices and the cylinder thermostat led to a reduction in the average temperature of the stored hot water, but only the cylinder thermostat maintained the maximum temperature at a safe level.
- The use of all tested devices led to significantly increased recovery times for the hot water cylinder.
- Device type C showed predicted fuel savings of between 8%-11% in the fully pumped system in the heating season. Average measured room temperatures were reduced during the operation of the device. It is concluded that the device only achieves savings by reducing the performance of the heating system.
- Device type B in the fully pumped system showed an increase of 2% in gas consumption. In addition, it reduced the average room temperature by 2°C. In the semi-gravity system, this device type achieves no predicted saving and has no effect on internal temperatures.
- Device type A achieves a modest saving of 4.3% in the semi-gravity system, but with a reduction in average room temperature.

The anti-cycling devices evaluated in this study were representative of those on the market. They led to some energy savings in the summer months in the poorly controlled system, but at similar levels to a cylinder stat and with poorer control of cylinder temperatures. Use of the products during the winter months led to some savings, but in all cases a reduction in heating system performance was demonstrated.

REFERENCES

[1] **Department of the Environment, Transport and the Regions.** 'Upgrading controls in domestic wet central heating systems – a guide for installers'. DETR, London, 1994.

[2] **Ott, Lyman.** An introduction to statistical methods and data analysis. 3rd Edition. PWS-Kent Publishing Company, Boston USA, 1988.

Further Reading

The Department of the Environment, Transport and the Regions' Energy Efficiency Best Practice programme has produced a range of Guides, Reports and Case Studies on domestic heating and hot water. Contact BRECSU at the address below for further details.

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